Jet Propulsion Laboratory
California Institute of Technology

Status of the Vapor In-cloud Profiling Radar (*VIPR*)

A New Method to Remotely Sense Water Vapor Within Clouds

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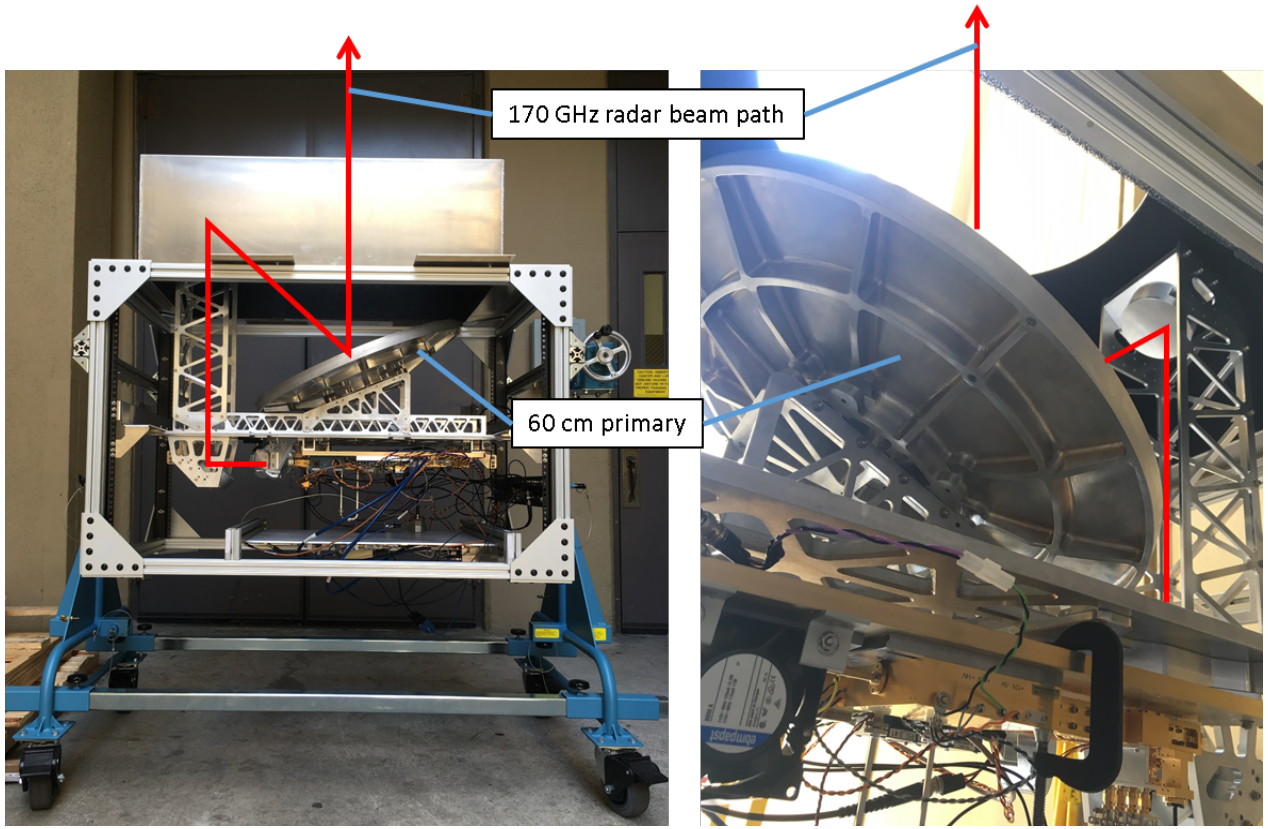
What is it?

- (VIPR) Vapor In-cloud Profiling Radar
- (DAR) Differential Absorption Radar
  - Microwave analogue of DIAL
- A concept to profile water vapor within the cloudy/precipitating atmosphere.
  - Complements existing water vapor observations
  - Addresses needs of the PBL incubation area of the Decadal Survey
- CWV measurements :
  - High spatial resolution
  - All surface types
  - Most storm conditions

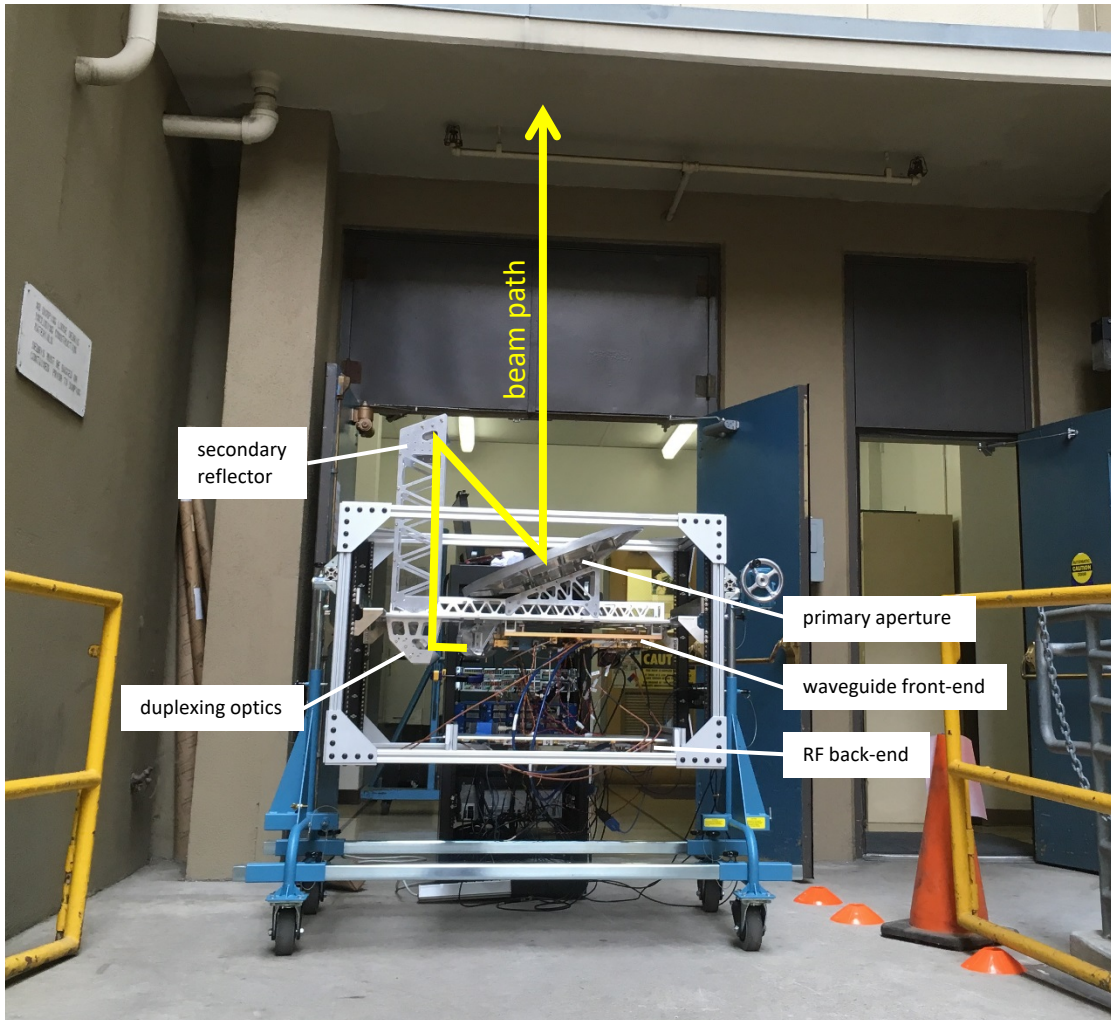
VIPR (Vapor In-cloud Profiling Radar)

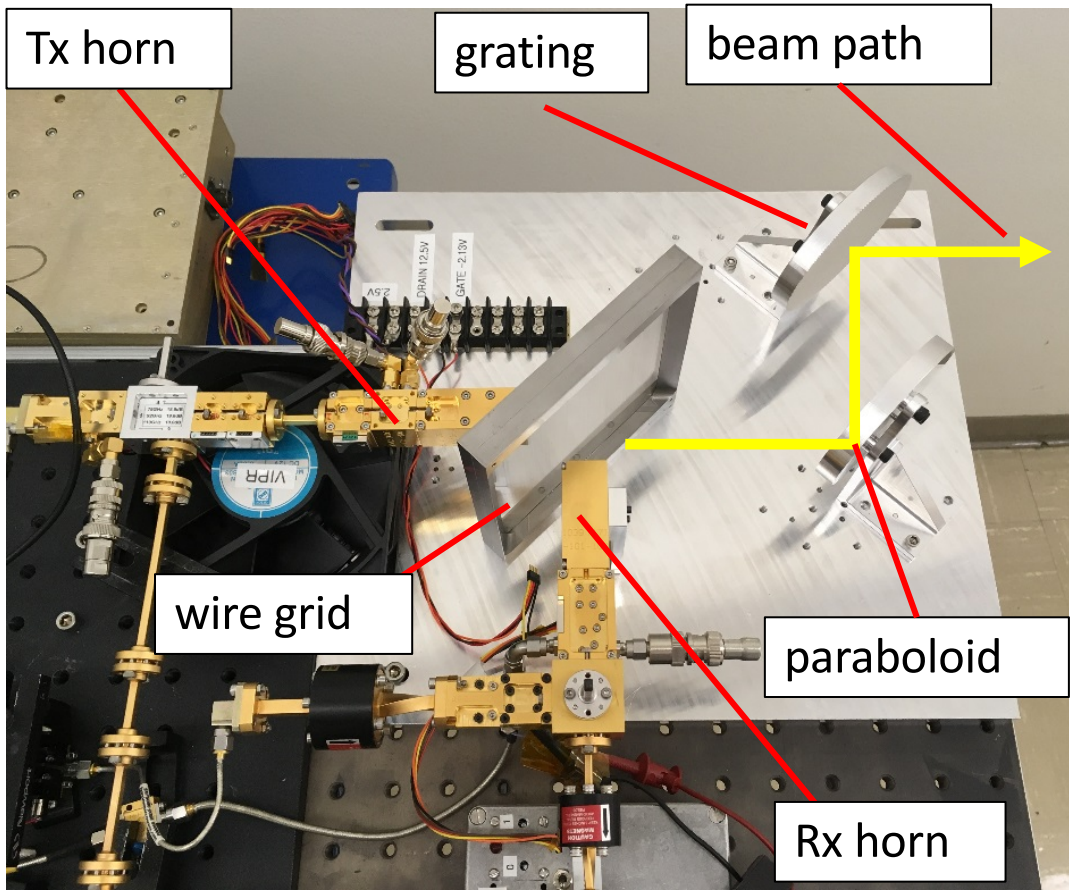
- Currently funded by NASA IIP-16
- Airborne demonstration instrument
- Target: boundary layer water vapor and column vapor
- Humidity uncertainty (<20%)
- Detection sensitivity (-30 dBZ @ 2 km)
- Entry TRL = 3, Exit TRL = 6 (*2020*)
- 0.5 W solid-state FMCW DAR
- 60 cm primary antenna
- Tunable bandwidth [167.1-174.7] GHz



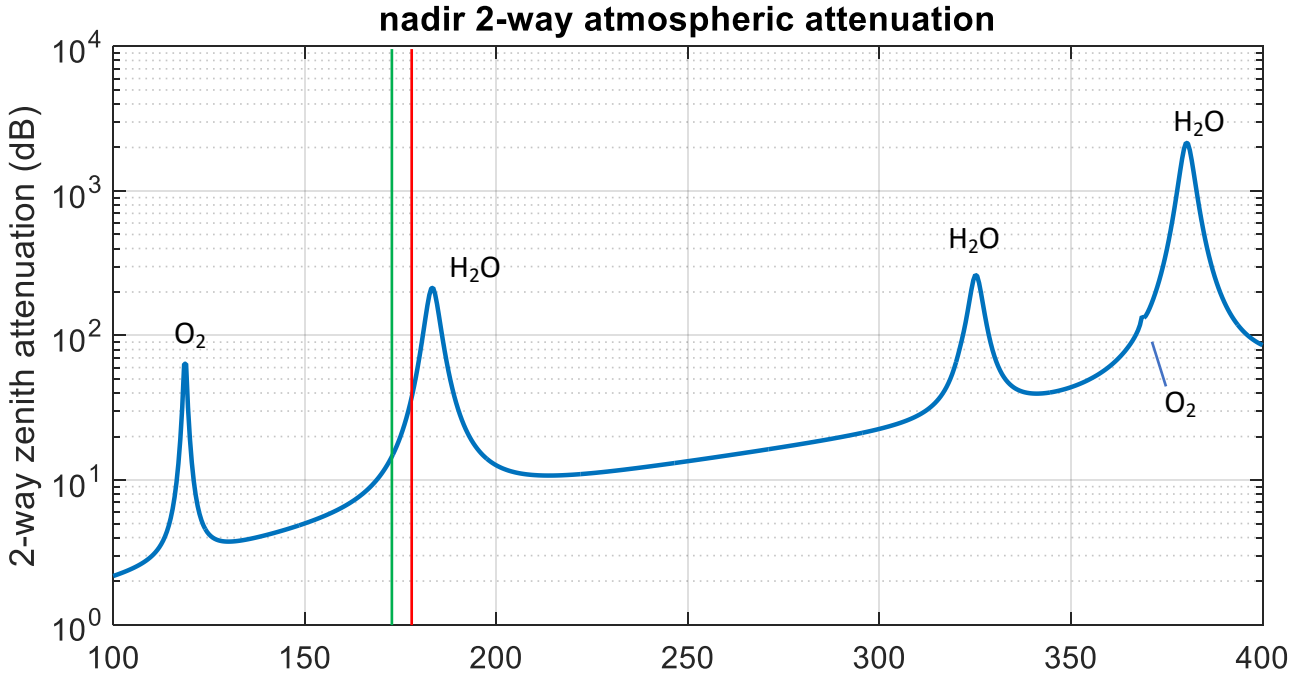
Airborne VIPR Development

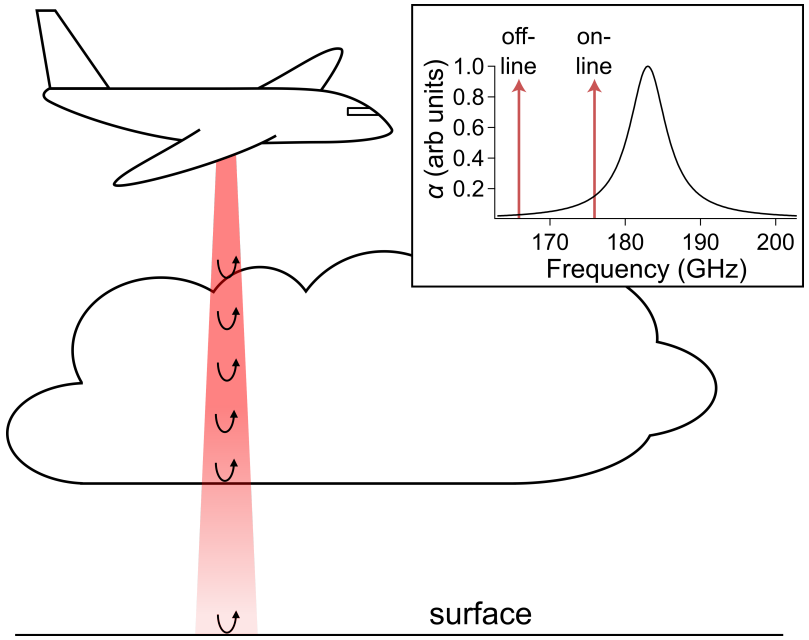
The VIPR system is mounted on Flotron rotation stage with the beam pointing upward. It uses a 60 cm diameter (58 dB gain) aperture.





Measurement Principle



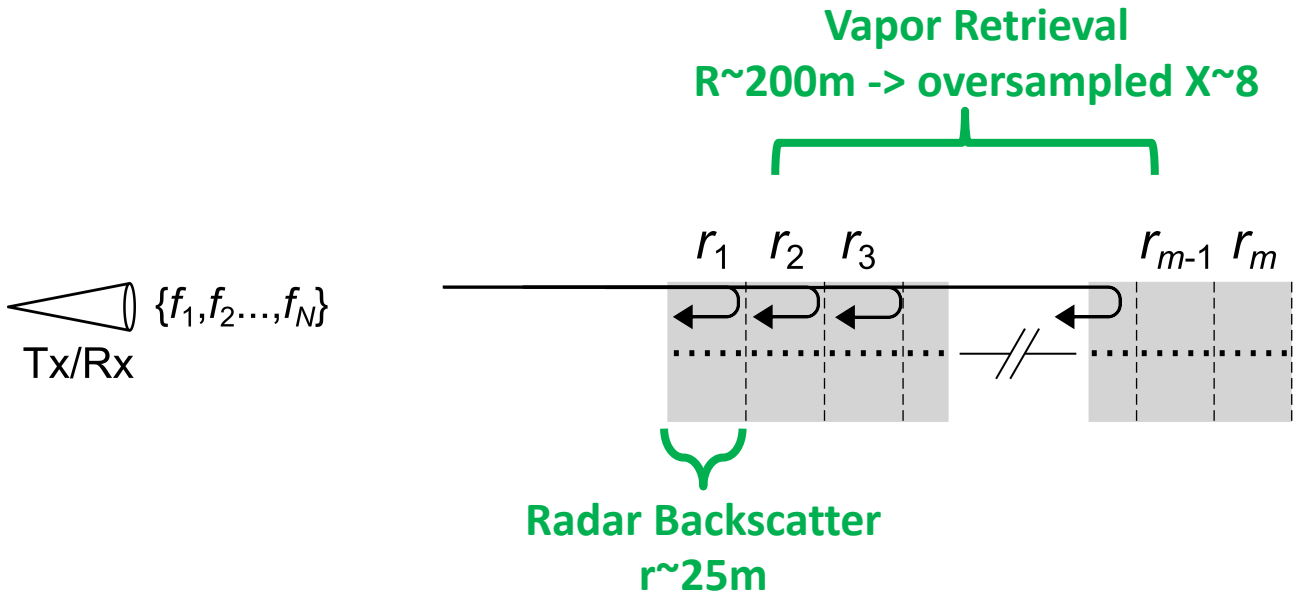


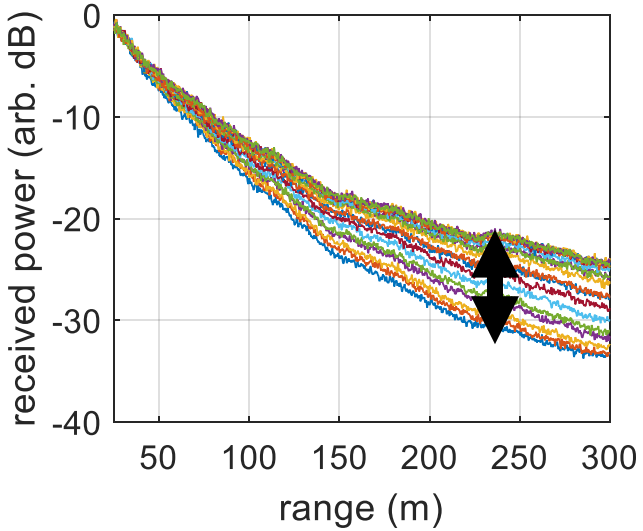
- Differential reflectivity from cloud/rain/surface is proportional to the gas density

$$\Delta Z \equiv dBZ(\nu_1, r) - dBZ(\nu_2, r) \propto u_{gas} = \int_0^r \rho_{gas} dr$$

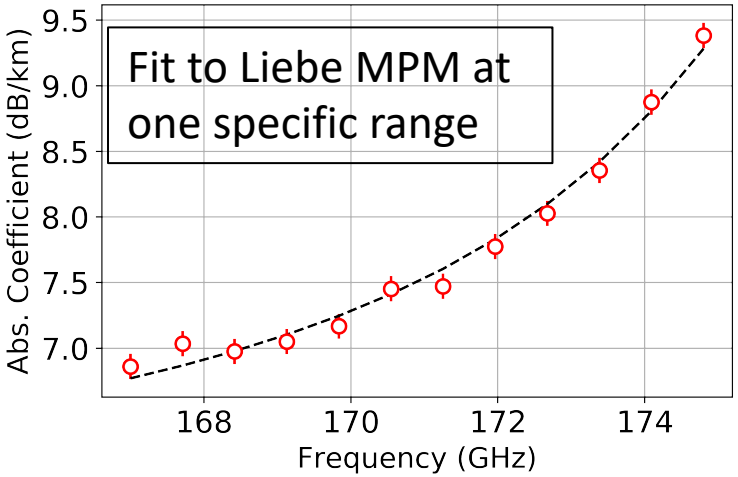
- *Assumption #1*: Unattenuated reflectivity is spectrally invariant (or variation is known)
- *Assumption #2*: Differential attenuation by liquid may be neglected (or variation is known)
- Key Benefits: Radar: provides range resolution / differential technique is self-calibration

Range-resolved water vapor profile retrieval



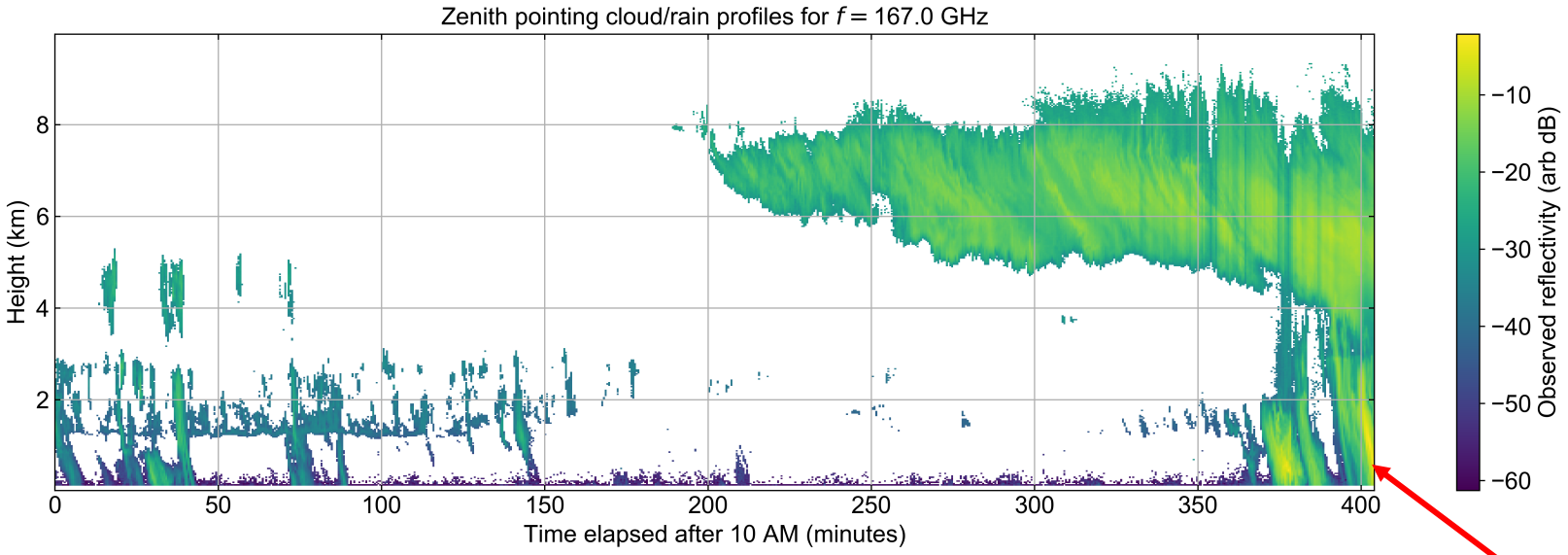


- Measurement quantity is differential attenuation per unit distance (a double difference)
  - Difference in range
  - Difference in frequency
- All instrument and range dependent terms cancel! *Self calibrating technique*

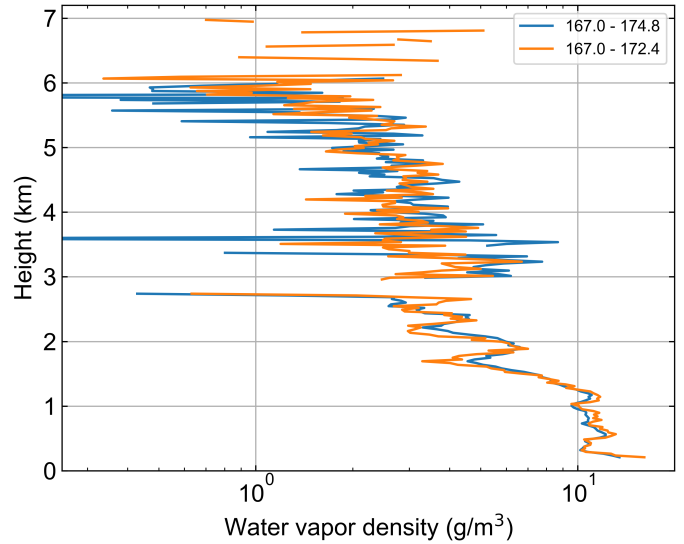


VIPR ‘first light’

Observed Power ‘Offline’



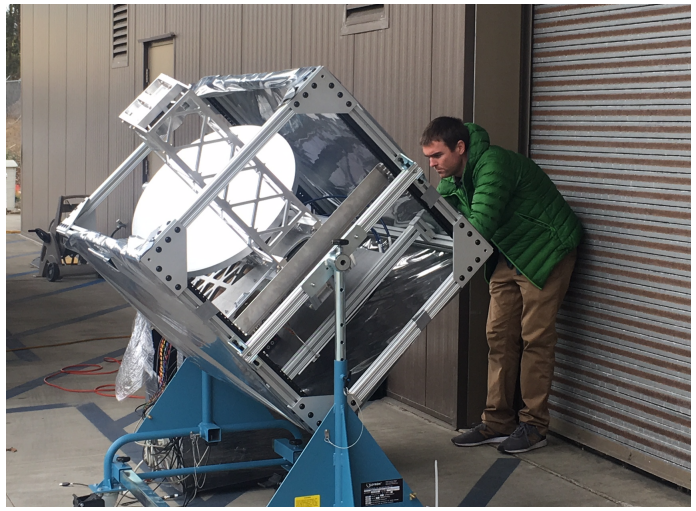
Derived humidity profile

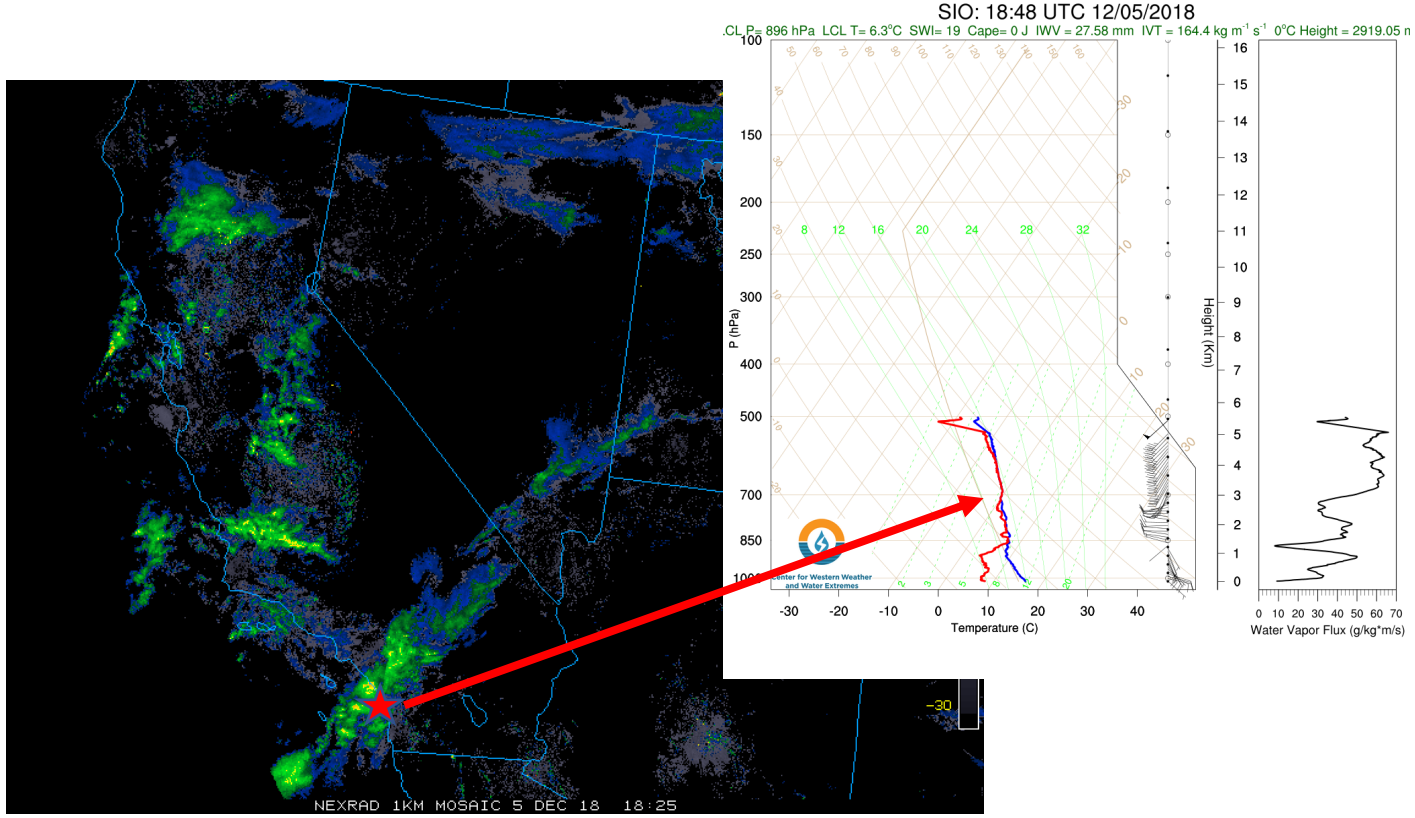


- First continuous curtain observations from VIPR
- High gain antenna allows detection out to 10 km
- Independent humidity retrievals show good agreement

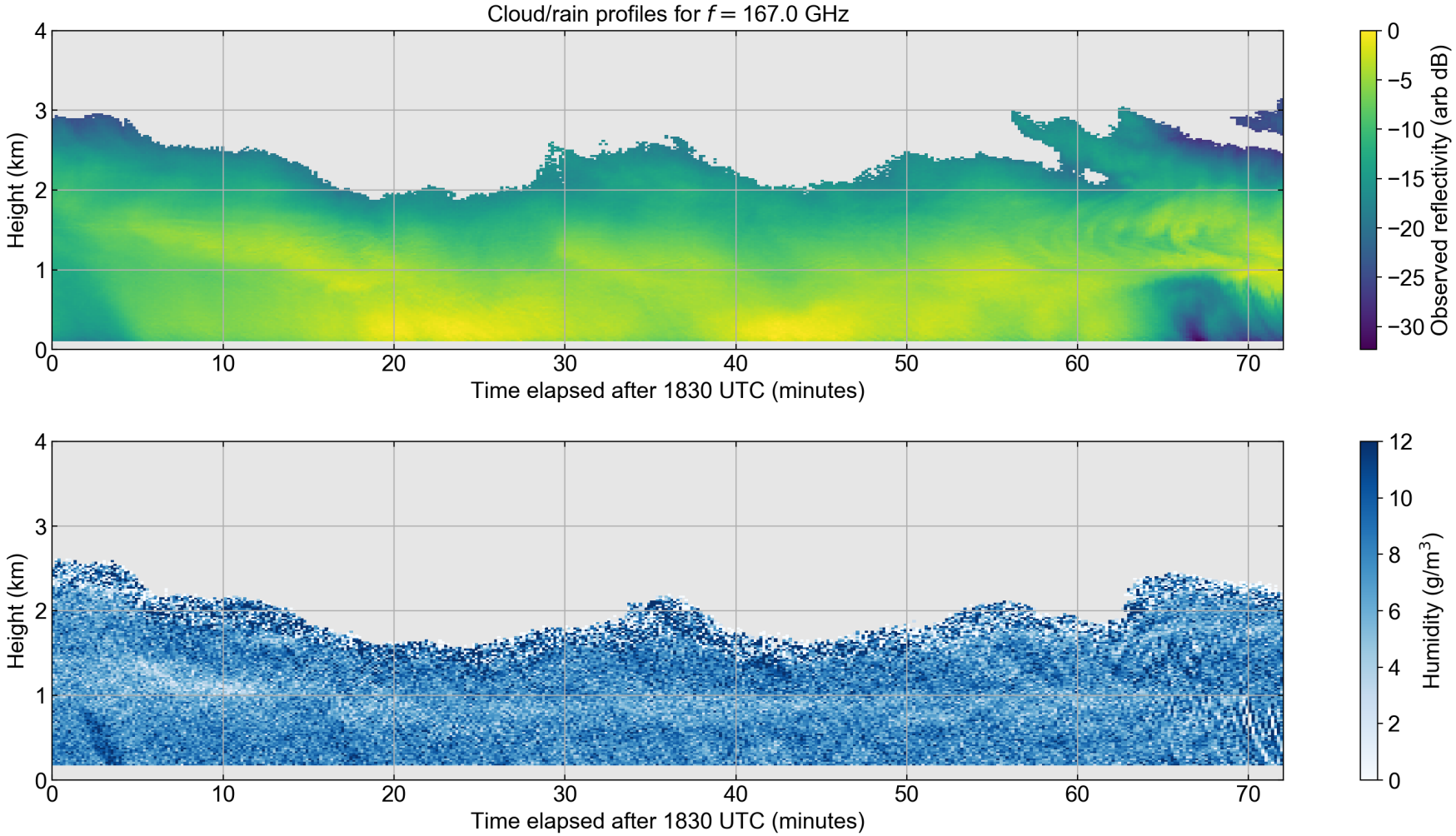
Recent Validation Activities

- Scripps validation deployment (12/5/2018)
- VIPR Observed 6 hours of a cold-frontal passage
- Scripps CW3E Launched 8 radiosondes





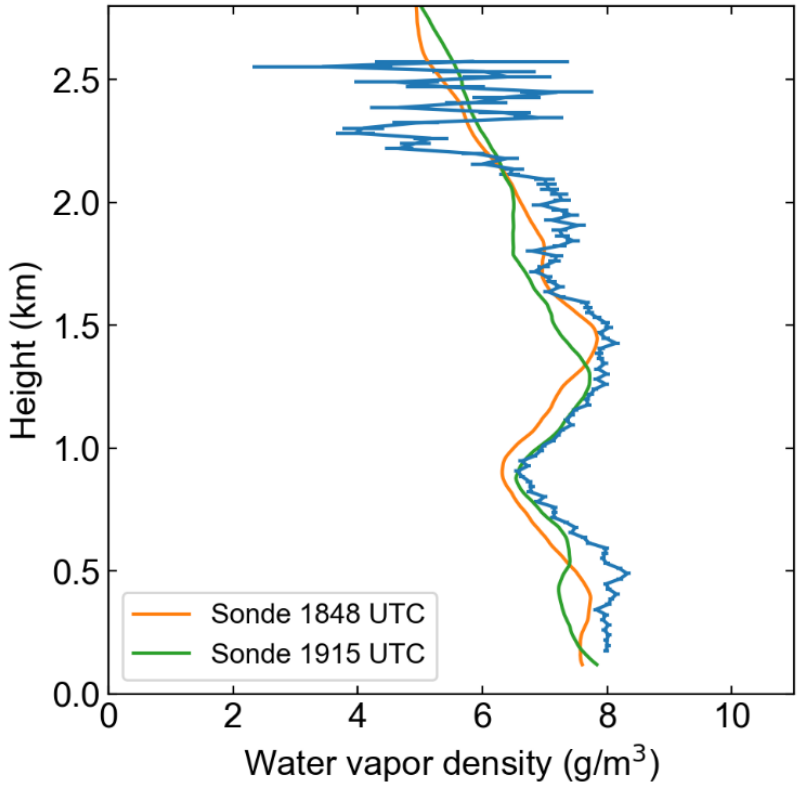
Initial Validation Results #1

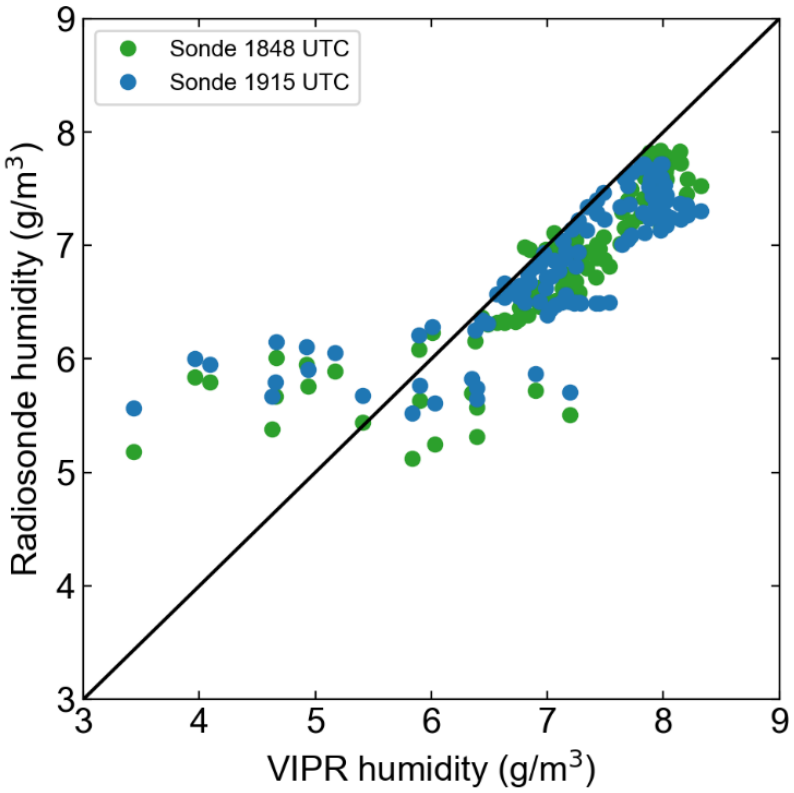


Initial Validation Results #2

RMSE(VIPR - sonde 1) = **0.59** gm^{-3}
RMSE(VIPR - sonde 2) = **0.66** gm^{-3}
RMSE(sonde 1 - sonde 2) = **0.31** gm^{-3}

Avg. bias(VIPR - sonde 1) = **0.28** gm^{-3}
Avg. bias(VIPR - sonde 12) = **0.28** gm^{-3}

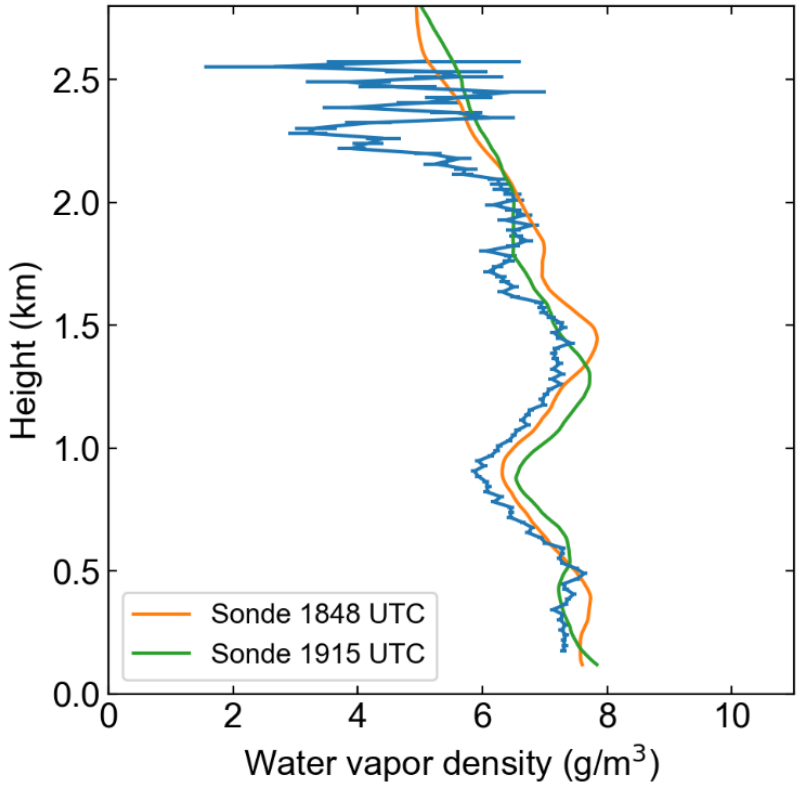


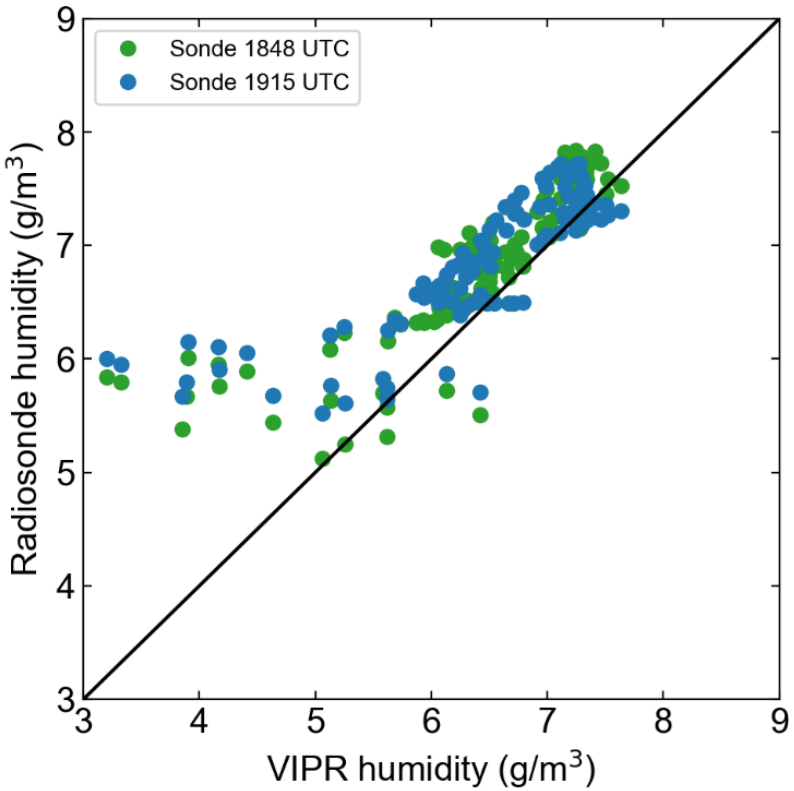


Initial Validation Results #3

RMSE(sonde 1848) = **0.70** gm^{-3}
RMSE(sonde 1915) = **0.75** gm^{-3}
RMSE(sonde 1 - sonde 2) = **0.31** gm^{-3}

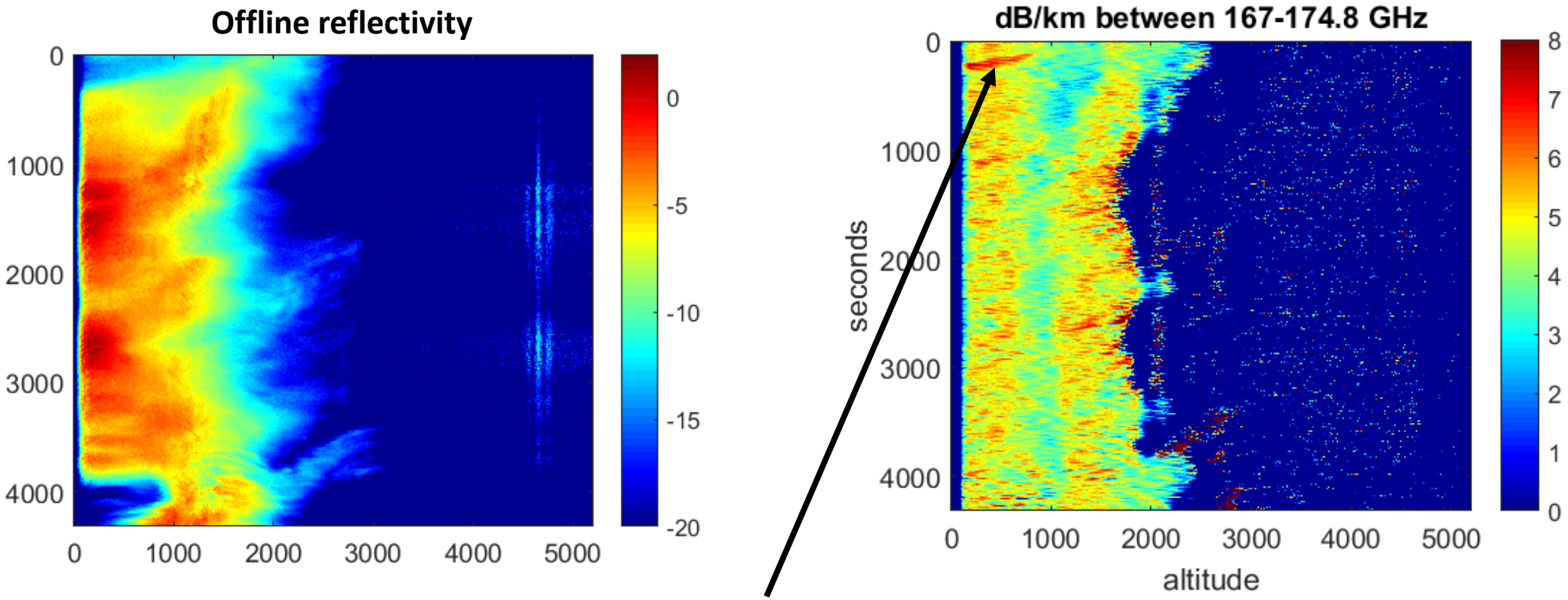
Avg. bias(VIPR - sonde 1) = **-0.45** gm^{-3}
Avg. bias(VIPR - sonde 2) = **-0.44** gm^{-3}





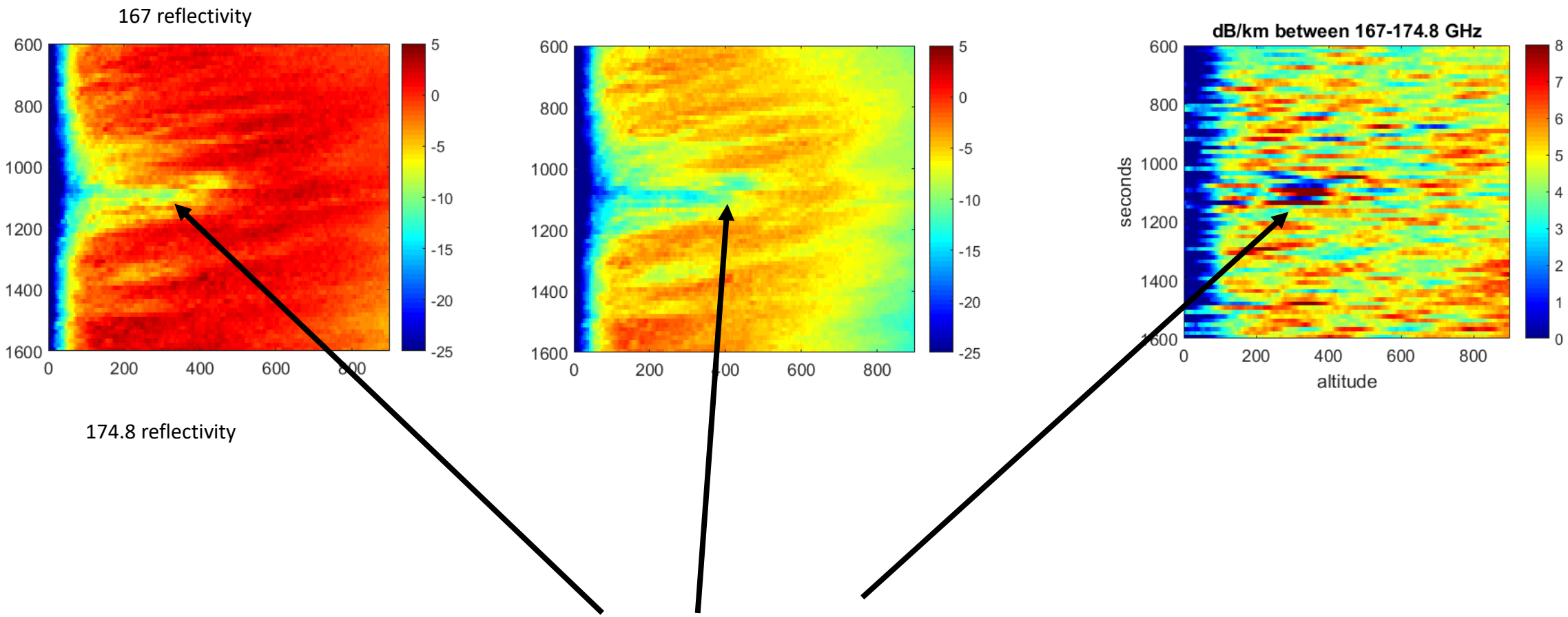
- Correcting for liquid attenuation (assuming Rayleigh) causes overcorrection

Suspicious Results



- Suspiciously large (40% increase) streaks of humidity are relatively common.
- Are they real?
- They tend to ‘fall’ down toward the radar.

Suspicious Results



- Gradients in the reflectivity associated with negative humidity!
- Clearly unphysical result seen more often than we would like.

What can cause bias?

Retrieved humidity

Actual humidity

Reflectivity bias

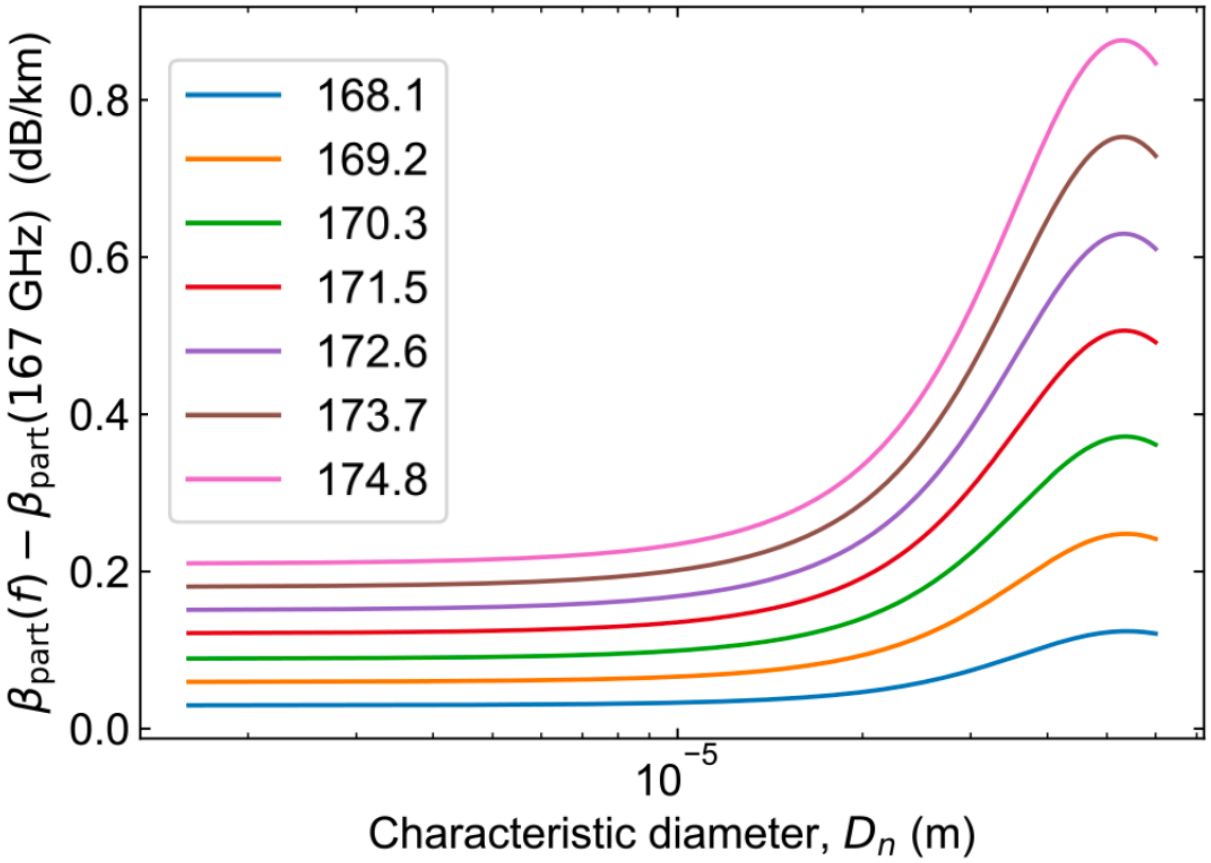
Particulate extinction bias

$$\tilde{\rho} = \rho + \underbrace{\frac{1}{2\Delta\kappa R}} \left[\ln\left(\frac{Z(r_2, f_1)}{Z(r_2, f_2)} \right) - \ln\left(\frac{Z(r_1, f_1)}{Z(r_1, f_2)} \right) \right] + \frac{\Delta\beta_p}{\Delta\kappa}$$

Differential mass extinction coefficient ≈ 0.3 dB/km/(g/m^3)

Differential Liquid Attenuation

Cloud water (500 gm^{-3})

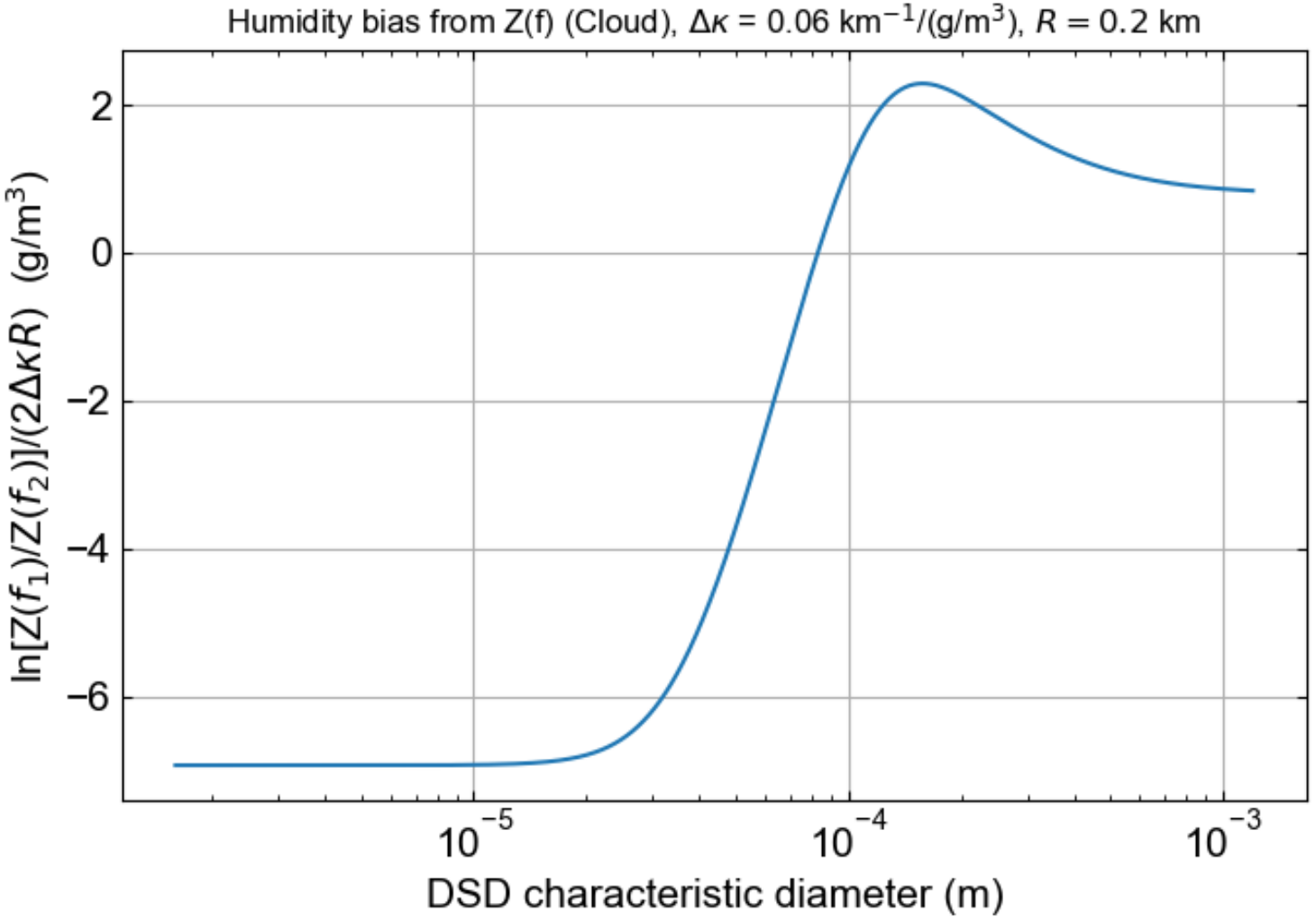


- Cloud water (Rayleigh) is fairly large
- Drizzle (~50 micron) very large
- Rain is very small

Differential Liquid Scattering

- Assume cloud at Range 2
- Precipitation at Range 1
- Range 200 m

- Extreme scenario yields extreme biases



Next Steps

- Demonstration/Validatation
  - Ground-based deployment to the ARM-SGP super-site (March 2019)
  - Airborne demonstration flights (October 2019)
- Continued investigation of hydrometeor scattering/absorption effects
- Algorithm and data processing improvements
- My Perspective:
  - PBL (thermodyanics) was called out for incubation activities over the coming decade
  - There is a need for coordinated airborne demonstration/validation with other PBL sensing instruments (e.g. lidar and passive sounders and dropsondes)